

Wright D, Clark J, Tiplady L. [Making learning visible in mathematics with technology](#). *Mathematics Teaching* 2015, 249, 30-36.

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**DOI link to article:**

<http://www.atm.org.uk/>

**Date deposited:**

04/11/2015



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# Making learning visible in mathematics with technology

David Wright, Jill Clark, Lucy Tiplady report on their on-going research

## Introduction

This article reports on the progress of a project called *Formative Assessment in Mathematics and Science Education* (FaSMEd, <http://research.ncl.ac.uk/fasmed/>). We are beginning to understand that *all* learning involves assessment and the project explores how this idea of '*learning as assessment*' is implemented across a number of countries in *both mathematics and science*. We believe that *formative assessment is a process which 'makes learning visible'* and closes the loop between learners, peers, and teachers with constructive feedback.

In 2013 the European Commission awarded a grant to a partnership of nine universities from eight countries, co-ordinated by Newcastle University, for a three year design research project to raise achievement in mathematics and science. The partners in the project are: the University of Newcastle upon Tyne, the University of Nottingham, the Ecole Normale Supérieure De Lyon, France, the National University Of Ireland, Maynooth, the University Of Duisburg-Essen, Germany, the University Of Turin, Italy, the Freudenthal Institute, University Of Utrecht, the Netherlands, the African Institute For Mathematical Sciences Schools Enrichment Centre, Stellenbosch, South Africa and the University College Of Trondheim, Norway.

The research was commissioned through the *European Commission Framework 7 programme 'Science in Society'* (research in the role of teaching methods and assessment methods in raising achievement in the field of Mathematics, Science and Technology) and is a collaborative development project. To support this action we decided to adopt a design research approach to the use of technology in formative assessment classroom practices that allow teachers to respond to the emerging needs of learners in mathematics and science. One of the aims of the project is to construct a '*toolkit*' for teachers which will exemplify some of the approaches trialled by the partners and their schools.

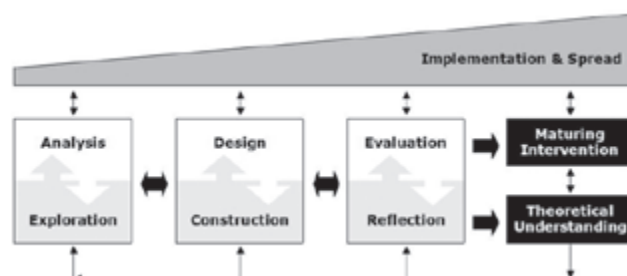
The project is now at its half-way point, and this article will focus on the mathematical activities trialled by our three school partners in the North East of England.

## Design research

What is '*design research*'? We are fortunate that one of our partners is Nottingham University so that we are able to draw on the experience and ideas of Professor Malcolm Swan the Director of the Centre for Research in Mathematics Education. One of his areas of expertise is in design-based research which he describes as a formative approach in which a product or process (or '*tool*') is envisaged, designed, developed, and refined through cycles of enactment, observation, analysis and redesign, with systematic feedback from end-users. Educational theory is used to inform the design and refinement of the tools, and is itself refined during the

research process. Its goals are to create innovative tools for others to use, to describe and to explain how these tools function, account for the range of implementations that occur and develop principles and theories that may guide future designs. Ultimately, the goal is transformative; we seek to create new teaching and learning possibilities and study their impact on end-users (Swan, 2014). An implication of this approach is that teachers are also equal partners in the research process.

A simplified diagram to illustrate this process is as follows:



McKenney and Reeves (2012)

## Crossing boundaries

In an international project like this, we have had to face the challenge of communicating across cultural, linguistic, and subject boundaries which has provided both opportunities and difficulties. Akkerman and Bakker (2011) provide an interesting survey of the main issues arising when boundaries are encountered or crossed. They point out that although these situations can be uncomfortable, they also provide opportunities for learning – particularly through dialogue and they identify four areas for discussion: *identity*, *co-ordination*, *reflection*, and *transformation*. This project is certainly engaged in crossing boundaries and our experiences so far provide ample opportunities for dialogic learning in questions of identity, achieving co-ordination, reflecting on issues and transforming practice. A particularly fruitful approach in these situations is to identify '*boundary objects*' (Akkerman & Bakker, 2011) which can serve as a focus for debate and dialogue. In the case of this project, the main objects providing the focus are: the concept of '*formative assessment*'; the creation of a '*toolkit for teachers*' and distance-time graphs.

## Formative assessment

The publication of '*Inside the black box*' (Black & Wiliam, 1998) and Hattie's (2009) survey of the effect size on achievement identifying feedback as a crucial element in learning has focused attention on '*formative assessment*' as a possible key to raising achievement. However, there are a wide range of interpretations of this concept, and we have had to devote a significant amount of discussion (which continues) to achieve some

agreement on what *formative assessment* might mean in our differing contexts. The original design for the project adopted the following definition:

*“... all those activities undertaken by teachers, and by their students in assessing themselves, which provide information to be used as feedback to modify the teaching and learning activities in which they are engaged. Such assessment becomes ‘formative assessment’ when the evidence is actually used to adapt the teaching work to meet the needs.”* (Black & Wiliam, 1998, para. 91)

In particular, we have agreed that formative assessment is a *process*, not a product. (A sister EC project, ‘Assess Inquiry in Science, Technology and Mathematics Education’ (ASSIST-ME: <http://assistme.ku.dk/>) has been very helpful in providing background research for our discussions). In adopting this approach it has become clear that professional development must be an integral part of our research and this has meant that ‘professional development’ has become another ‘boundary object’ where differing cultural conceptions meet. We have found a helpful mantra in our work (adopted from Hattie) is that formative assessment is ‘Making learning visible’ for both teachers and learners.

We have adopted the following diagram to provide a structure for our work:

Where the learner is going	Where the learner is right now	How to get there
Teacher		
Clarifying learning intentions and sharing criteria for success (A)	Engineering effective classroom discussions, activities and tasks that elicit evidence of learning (B)	Providing feedback that moves learners forward (C)
Peer		
Understanding and sharing learning intentions and criteria for success (A)	Activating students as instructional resources for one another (D)	
Learner		
Understanding learning intentions and criteria for success (A)	Activating students as the owners of their own learning (E)	

Wiliam & Thompson, 2007

The focus of the activities and professional development for the project have concentrated largely on categories B-E (labelled in the diagram above), whilst ensuring that learning intentions and criteria for success are clearly signalled in planning the activities. The point of this focus is that we believe that the greatest challenge for teachers and students is to ‘close the loop’ where effective feedback provides a way forward for learners. We believe we are adding to this well-established ‘Assessment for Learning’ framework through our choice of activities, processes, and technology towards a situation where ‘making learning visible’ becomes ‘Assessment AS Learning’ (Hickey, 2011).

## Re-engaging vs Re-teaching learners

Another challenge for the project is learners who are regarded as struggling. Since the focus of the project is on raising achievement we have encouraged schools to work with classes where the school thinks that the students are under-achieving in some way, or selecting classes which include the full range of attainment. Established approaches for working with such students are frequently characterised by a ‘deficit’ model of their potential which entails repeating material from earlier years, broken down into less, and less, challenging tasks, focused on areas of knowledge in which students have previously failed and which involve step-by-step, simplified, procedural activities in trivial contexts. In contrast, we have adopted activities from the *Mathematics Assessment Project* (MAP) (<http://map.mathshell.org/>) which are nicely summarised by the following diagram used in the *Silicon Valley Mathematics Initiative* (<http://www.insidemathematics.org>)

Re-Teaching	vs.	Re-Engaging
teaching the unit again		revisiting student thinking
addressing missing basic skills		addressing conceptual understanding
do the same problems over		examine the task from different perspectives
more practice; learn procedures		critique approaches, make connections
focus mostly on underachievers		engage entire class in mathematics
cognitive load usually lower		cognitive load usually higher

The approach of MAP is that learning occurs through active participation *in* and reflection *on* social practices, internalisation and reorganisation of experiences in order to activate pre-existing concepts and ideas. Hence, mathematical activities should stimulate ‘conflict’ or ‘challenge’ to promote re-interpretation, reformulation and accommodation. In addition the aim is to devolve problems to learners so that learners articulate their own interpretations and create their own connections. Perhaps what is most challenging in the present context in England is that MAP believes that ‘productivity’ must give way to reflective periods for examining alternative meanings and methods.

In other words, the focus of *FaSMEd* is to challenge learners in a context where technology and appropriate support allows them to deal with an increased cognitive load, increasing their capacity rather than reducing it.

## The place of technology

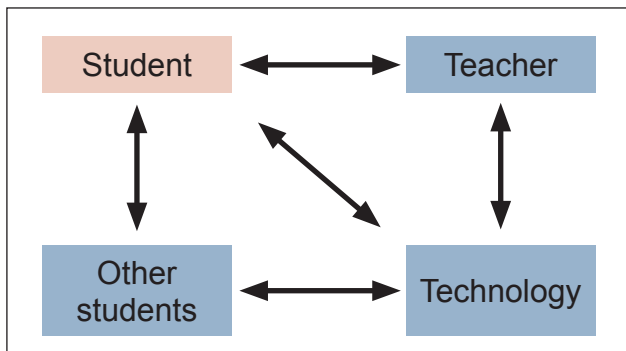
Throughout history people have searched for tools to support their learning and thinking, but relatively few have found their way into the classroom and fewer have been adopted consistently and constructively. Digital tools and technologies are another addition to this collection, but although they have been available to schools in the developed world for decades, the evidence for their positive impact is at best equivocal (Higgins et al, 2012).

Indeed, although some tools such as projective technology have been widely adopted a recent critique summarises many digital innovations as putting: *‘technology above teaching and excitement above evidence’* (Luckin et al, 2012 p.63).

Fullan and Donnelly in a recent publication (Nesta, 2013 p10) list four criteria for effective adoption of innovative technology:

1. Engaging for both students and teachers
2. Easy to adapt and use
3. Ubiquitously available
4. Steeped in real life problem solving

Hence the digital applications chosen by our schools are relatively simple, and are chosen to reinforce our pedagogical approach incrementally through improving the communication flows in the classroom.



The use of digital environments in classroom in recent years has changed from a more private to a public use that integrates private use (Hegedus & Moreno-Armella, 2009; Robutti, 2010). This shift, which echoes the historical shift from the use of individual handheld slate to blackboards, is recognised by recent literature about the relationships between the use of private activity (individual or in small groups) and public activity (to which all the students participate). The public screen not only displays the student work in real time, providing immediate feedback, it enables individual students to compare and connect their own work with that of others. In addition, the rapid development of small mobile devices gives an opportunity for students to access technology as, and when, they need it in the classroom.

In discussion with our partners we have provisionally classified the function of technology in formative assessment in three categories:

1. Sending and Sharing
  - *the technology facilitates sharing information as a communication channel*
2. Processing and Analysing
  - *the technology aggregates data from student responses and/or provides some feedback which might be simple right/wrong or more complex*
3. Interactive Environment
  - *the technology provides a mathematical environment where the learner can explore and make choices and see the outcome – e.g. dynamic geometry*

It should be noted that our South African partners do not use digital technology in their activities, because of the difficulties in resourcing such high-tech tools. However, we include their use of such tools as posters, card sorting, and low-tech feedback devices as mini-whiteboards in this scheme in the 'Sending and Sharing'

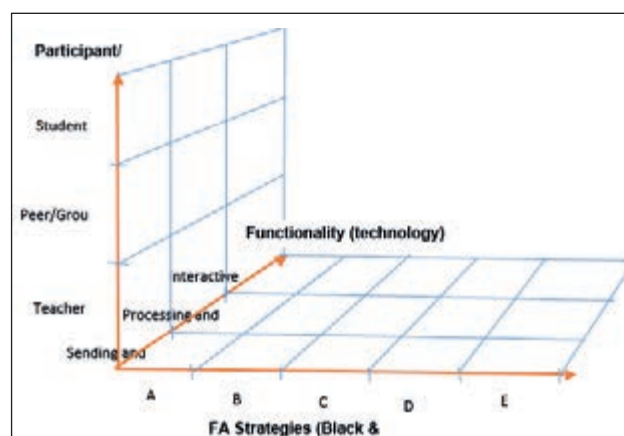
category. These too are ways of 'making learning visible'.

### Mapping the activities

The classification of digital technology and the Wiliam and Thompson categories have allowed us to start to map out the space of approaches adopted across the project in three dimensions:

1. The participants: teacher, peer or student.
2. The formative assessment process A – E from the Wiliam and Thompson table
3. The use of technology.

The following diagram illustrates this space.



This diagram, developed in discussion with our partners, also acts as a boundary object for the project because it allows us to understand where the activities and tools used by all the partners fit into this space. In addition, we can see where there are gaps which might need to be addressed in the future. The diagram is a *work in progress* which is supporting our understanding of how technology can support formative assessment and will be further refined and developed with our partners as the project continues.

### Examples from classrooms

In the North East of England we are using a 're-design' strategy, drawing on already existing materials to investigate how the addition of digital technology can enhance the formative assessment process in the classroom. The materials we are using are from the *Mathematics Assessment Project* (MAP) resource developed by the Centre for Research in Mathematics Education, Nottingham University and the University of California, Berkeley (<http://map.mathshell.org/>). Supported by the *Gates Foundation*, this website includes 100 formative assessment lessons, some focused on developing mathematical concepts, others on solving non-routine mathematical problems. *FaSMEd* is investigating how the addition of technology can enhance these activities. Our three schools have all agreed to use a lesson based on time-distance graphs, and then chosen five lessons from a selection of non-routine mathematical problems. The reason for this decision is that the time-distance activity is a boundary object for the project across cultures and subjects, it occurs in both mathematics and science, and will assist our cross-cultural comparison study of such activities since all schools and partners will be doing it – the non-routine problems are easier to fit into existing schemes



of work, and the focus on problem solving is a welcome supplement to departments who are adapting to the new GCSE requirements, although most of the classes are in KS3.

The following description, drawn from the *Mathematics Assessment Project Guide*, describes the process used in the lessons:

*“Concept development lessons focus on assessing and developing students’ understanding of significant mathematical concepts, the interpretations that students have of the concepts and the connections between the concepts and their other knowledge...”*

*They follow a format and flow that, with some variations, involves the following phases: Prior to the lesson, a day or so before, the teacher assigns the pre-assessment that students complete individually. These typically take 10 to 15 minutes and are diagnostic, designed to reveal each student’s understanding and misunderstandings of target concepts. The teacher reviews and analyses the students’ responses to gain an overview of the understandings and misunderstandings. Instead of scoring the papers, teachers are encouraged to create questions that will help students’ reflect on specific issues they need to address. ...*

*The lesson has teachers engaging students in a related task, designed to expose their different ideas and ways of thinking. The tasks are rich and complex, allowing struggling students to gain access, while still providing challenges for the most capable. Students become aware of the inconsistencies in their own conceptions. This awakens a curiosity and desire to seek resolution through discussion. During this work, the teacher listens carefully to students and uses questioning (including the pre-prepared ones in the Lesson Guide) to promote deeper thinking and reflection. At various points, whole class discussions are used to share and resolve common difficulties. The lesson concludes by sharing the different understandings and by generalizing and extending what has been learned. Students explain what they have done, and found. After the Lesson students are given a post-assessment, similar to the pre-assessment, to demonstrate their learning from engaging in the concept lesson.” (MAP Guide for teachers, p 3)*

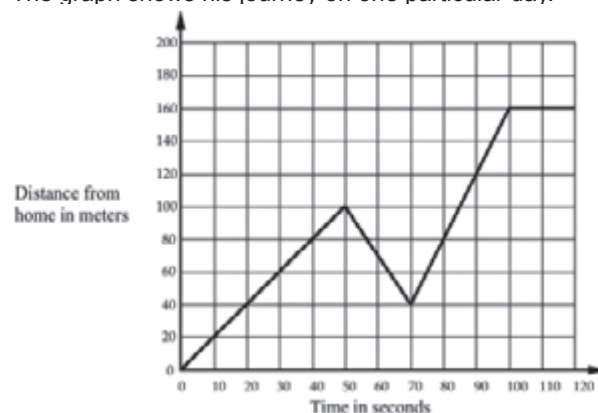
### Example of a concept development task:

Time-distance pre-assessment (© 2012 MARS, Shell Centre, University of Nottingham)

### Journey to the Bus Stop

Every morning Tom walks along a straight road from his home to a bus stop, a distance of 160 meters.

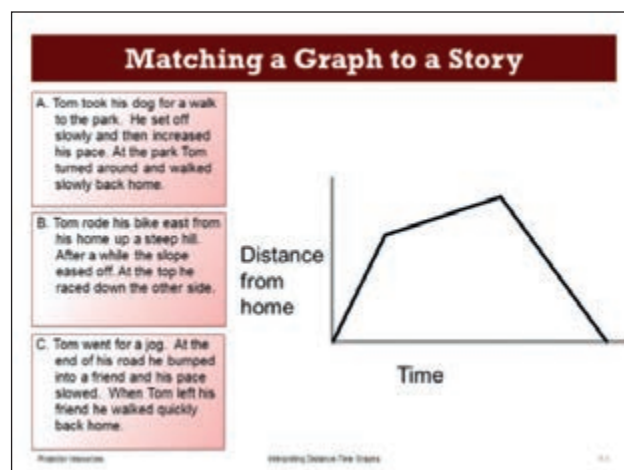
The graph shows his journey on one particular day.



1. Describe what may have happened. You should include details like how fast he walked.
2. Are all sections of the graph realistic? Fully explain your answer.

Formative assessment discussion question

– designed to be projected for a whole class discussion:



The role of technology in this lesson is to capture and to share student solutions, and to stimulate discussion through capturing and aggregating student responses to the above question via a ‘poll’ using *Socrative* ©, or *Classflow* © software or similar.

### Problem solving lesson

Problem solving lessons follow a similar format:

*“Problem solving lessons are designed to assess, then develop, students’ capacity to apply their mathematical thinking flexibly to non-routine, unstructured problems, within math and from the real world – problems that students have not been taught how to solve. The challenge includes deciding on a strategy to solve the problem, applying the strategy, and then checking the solution to see if it works. The lesson design is built on using sample student work, which is provided. The students are asked to compare different approaches to a specific problem, understanding, critiquing, and learning from them....*

*Prior to the lesson, a day or so before, the teacher assigns the task for students to complete individually. These typically take 10 to 15 minutes. The task is an unstructured non-routine problem, designed to reveal students' capabilities and limitations in problem solving. The task remains the focus throughout the lesson. The teacher assesses the students' responses to the task, noting their approaches to the problem and their difficulties. Teachers are encouraged to give feedback to their students by creating questions that will direct students' attention to strategies for problem solving. ...*

*The lesson: Students begin by individually reviewing their own solutions to the task in light of the questions raised by the teacher. After this reflection, students move into small groups to compare and build on their strategies for the problem. The teacher's role is to observe the groups, looking for different approaches and support their collective problem solving through questions like those suggested in the Lesson Guide. The teacher facilitates the sharing of different approaches in a whole class discussion, with selected groups explaining their strategies. The students are then given some sample student responses for the same problem to discuss in their groups. The sample responses show a range of approaches at different levels of completeness and mathematical sophistication. The work includes solutions using numbers, tables, graphs and/or algebraic reasoning. The students are asked to analyse and critique the work, compare solutions, and comment on their strengths and weaknesses. After the lesson students work alone, again, to improve their individual solutions to the task and/or engage in a final reflection on what they have learned."*

(MAP Guide for teachers, p 4)

These lessons are designed to occupy several hours work, and teachers are finding that it can take up to a week to complete them.

### Pre- assessment task

### Design a Candy Carton

• A candy company wants a carton that will contain 18 candies.

Your design must take into account the following:

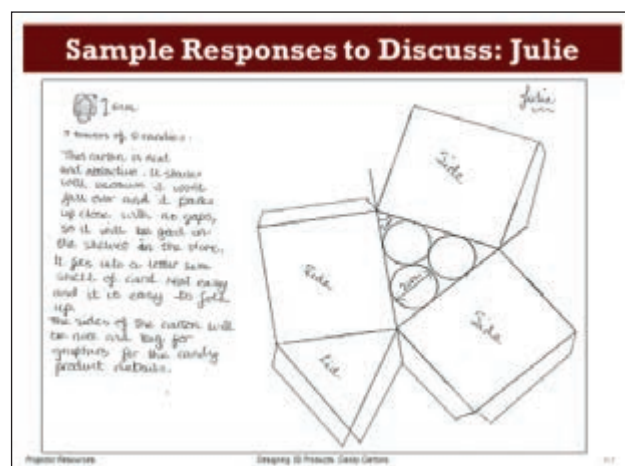
- The candies are each 1 cm deep and 2 cm in diameter.
- The carton must be made from a net that fits on a single sheet of letter-sized cardboard.
- The design should require as little cutting as possible.
- The sides of the carton will be fixed together using glue flaps. Show where these will be on your net.



Produce two possible designs for nets of the candy carton. Compare your two designs. Record in writing which carton you think is best, and why.

In the full lesson, students return to their designs and work in groups to improve and construct the cartons. They are then given some 'sample' solutions to critique. This is a key step in the formative assessment process where students and their peers themselves engage in an assessment of other solutions in order to develop their self-assessment skills.

### Example of a sample solution



### Technology

Our three schools chose a variety of technology, which were funded through the FaSMEd budget, two using iPads and another using Chromebooks. There was also a range of techniques used:

- School A has only one iPad per class, the main use of which is for the teacher, or student, to photograph their work and project it for the whole class to see. The software used allows the student to annotate their work as they talk to the whole class from their place in the classroom to discuss their solution. Teachers are also using it to photograph students' work at various stages, in order to bring to department meetings for discussion
- School B has a class set of iPads. In addition to the projection of solutions for discussion they are being used to poll students about their responses to a number of key questions at 'hinge' points in the lesson and for tracking students' responses.
- School C has a class set of Chromebooks, these are used with Googledocs in order for the students to share their work with each other and the teacher online, and also through the class projector.

### Professional development

The teachers, in each mathematics department involved in the project, committed to a series of in-school project meetings to support a 'plan, do, review' cycle covering approximately three weeks for each activity. In other words, meet to plan the activity in week 1, carry it out the following week 2, and review it in week 3. We encouraged the development of a 'teacher learning community' in each school to support the philosophy that this design research project included teachers as equal partners in it and our researchers joined most of the meetings held. In practice, the way in which this happened was determined by each school's policy on time allocated for professional development and there was a range of responses. The three schools also came together in a 'cluster' meeting four times over the course of the project to share information, to discuss approaches, and to plan.

Teachers were asked to evaluate each lesson and provide a report for the University research team. Each

department was free to choose the activities, so a wide range of lessons were trialled. Where the same activity was chosen, but not simultaneously, teachers and researchers were able to share approaches and issues with the subsequent schools during facilitated project cluster meetings.

### Outcomes

The project has generated information which will form the basis of a number of case studies, one from each of the North-East of England schools, illustrating how teachers and students have adopted these tasks and technologies. These will be collated and compared with case studies from our international partners, two from each partner, and used to exemplify a range of approaches as part of the online 'toolkit'. A *work-in-progress* prototype is available at <https://toolkitfasmed.wordpress.com/> which is one of the major 'deliverables' of the project.

Teachers' comments indicate that the format of the assessment lessons has been beneficial; in particular they found that the 'pre-assessment' tasks provided valuable data to support their planning for teaching.

*"The idea of using a pre-task (and post task) is excellent for assessing what students know, how students are making progress and which students need extra support."*

*"The information gleaned from the pre-assessment tasks has always proven to be invaluable in finding out where the stumbling blocks for the students are, and where teacher intervention is required. While the barriers for completing the task is sometimes similar for all students – and where I would have probably expected – occasionally it has thrown up surprises. This is a highly transferrable strategy which I plan to use before all units of work to inform my planning for the group."*

The activities appear to have enhanced the shift in teachers' thinking from *what they are teaching* to *what the students are learning*:

*"By far the most beneficial thing for me has been the tasks and although I have a thought process in mind as to how the lessons might go I have not always foreseen where they actually end up going. It has improved my questioning skills because I have had to think like the learners and try and identify their thought processes and develop these rather than guiding them the way that I have wanted to go."*

There have been some other shifts in practice and perspective too:

*"The FaSMEd project has reinvigorated my every day teaching and made me think about how I approach lessons and their structure. I am already starting to use photographs of students work (displayed anonymously) to aid discussion and model working out/explanation. I already do a lot of pair work, but I am thinking more carefully about which students are paired together and I'm trying to mix students up more."*

*"The most surprising aspect of the lesson was at the very start when the students were told to work independently. They class don't do that much*

*independent work – they do a lot of group work – I was a little nervous some might struggle to access the problem. As expected some did not know what to do at all to start with, but surprisingly after 15 minutes in completely independent conditions every student managed to write something on the assessment and every student wrote something mathematically useful. This was refreshing for me to learn that everyone in the group had the ability to approach the task and to learn that some students needed the extra thinking time before writing. It was rewarding to then see these students contributing in the group work because they had something to say."*

Where teachers have attempted more ambitious uses of technology there were some inevitable problems which could have discouraged them from attempting to use it again. This is where the benefit of collegial support became more apparent.

*"I am, by nature, a technophobe. By pushing my boundaries in engaging with this task I have explored pedagogical approaches that I might have otherwise not. This certainly would not have happened on my own. The mutual support of other colleagues, sharing both successes and the "failures" is crucial."*

*"The opportunity to work with a different group of colleagues has been excellent and I have learnt a lot about technology from them."*

However, technology also had its benefits:

*"The use of Socrative helps me to access the views/ ideas of all students. Students like the anonymity of seeing their responses without other students knowing who made them. They feel more able to explain their ideas and to express themselves. This helps to promote whole class discussion."*

The quality of student work and engagement appeared to be much higher in the trial lessons, and this was because of the key role that technology played in displaying their work to their peers.

*"If they know that they are going to have to present their work to the rest of the class they make much more effort with it."*

### Student outcomes

We are in the process of analysing the data from observations, questionnaires, interviews and other activities with the students involved in the project, so detailed outcomes are not yet available but students will have a voice in the project. For example, one approach that we are developing is in working with a group of students to produce a 'comic' which will tell the story of their experience.

However, teachers have noted that, for example, students understanding and retention of interpreting distance/time graphs is significantly better than comparable groups.

*"The raising of student achievement is difficult to measure. I feel that my students are more confident in approaching unfamiliar tasks. They are more likely to 'have a go' at a task. The need to share work with their partner and to improve their own work, has helped them to appreciate the need to get something down on paper and to try things out. It has also*



*helped their accountability in needing to complete a task, rather than just saying say 'I don't know what to do'."*

## Conclusion

The *European Union FP7* programme has funded a considerable number of educational interventions and innovations like *FaSMEd* (see <http://www.scientix.eu/> for other examples such as *PRIMAS*, *Mascil*, and *EdUmatics*) and we need to have a realistic evaluation of their likely impact. Education history is littered with innovations and interventions which appeared to have potential but evaporate after the initial enthusiasm, or funding, dries up. A tool which may provide such an evaluation is the '*innovation index*' devised by Fullan and Donnelly (Nesta, 2013).

Since we are just half way through *FaSMEd* an evaluation difficult to do, but using the *innovation index* we have identified that although it is strong pedagogically, further work needs to be done in supporting the use of tools, and in considering how it might have a more systemic impact.

What is clear from our engagement with a range of mathematics departments is the tension in the classroom between productivity and the need for students, and teachers, to have time for reflection. It was noted that it was unusual for classes to spend a relatively prolonged time on a project and the question was – '*Is this wasting time? Could I have covered this in one lesson?*' Once again this raises the issue of shifting focus from teaching to learning.

We are hopeful that our international context will provide an informative range of case studies, from around the world, on how technology can be used to support formative assessment in mathematics and science classrooms in a range of cultures.

Moreover, we are developing a richer understanding of assessment and its place in learning: all learning involves assessment, because all learning involves interaction.

*"In every moment of interaction, participants produce information that reflects their current understanding of each other's statements and intended meanings, and this information plays a major role in the way the interaction progresses. In this sense, assessment is inherent in all interactions, although the function of assessment is, for the most part, tacit".*

(Greeno & Gresalfi, 2008, cited in Hickey, D. (2011))

In other words, we are moving to an understanding of assessment as learning. (Hickey, 2011)

QR  
Code

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Note: for more information about the project download a guide here: [http://map.mathshell.org/guides/map\\_cc\\_teacher\\_guide.pdf](http://map.mathshell.org/guides/map_cc_teacher_guide.pdf)

## Acknowledgements

Thanks to the teachers from George Stephenson High School, Killingworth; Park View School, Chester le Street; St Thomas More RC Academy, North Shields and Langdon Park School, Tower Hamlets.

*This project has received funding from the European Union's Seventh Framework Programme under grant agreement no 612337*

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